Crea8 Sustainability Challenge

IHL007

Hougang Mall

Nanyang Junior College

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Introduction

We are a group of students from Nanyang Junior College who are passionate about improving the sustainable efforts in our country. After much thought and consideration we have decided to choose Hougang Mall to be the building that we would want to improve in terms of energy efficiency, greenery integration and water efficiency. We have come up with a myriad of innovative ideas that could potentially help to improve the sustainability of Hougang Mall. Additionally we have tried our best to come out with the estimated cost analysis, maintainability and the pros and cons of each suggested strategy.

To improve energy efficiency, we have decided to implement a parking app that allows cars to find a parking slot efficiently, thus reducing the amount of heat that is liberated from the engine. Additionally, we have come up with solar output sensitive windows that will absorb solar energy and convert it into electrical energy.

To implement greenery integration into the mall, we will be setting up vertical gardens on the exterior and interior walls of the mall and also at the rooftop.

To improve water efficiency, we would be setting up grass patches on the rooftop where water is able to infiltrate through and be stored. The water would be used for cleaning the mall.

Proposed Improvement for Energy Efficiency

Introducing “ ParkWise”

Problem

Underground car parks are heated by waste heat from car engines and are typically several degrees warmer than the surrounding subsurface. This would result in an increase in heat absorbed by Hougang Mall, thus resulting in the increased usage of energy for cooling.

Upon entering the car park, drivers may face delays in locating a parking spot, especially during peak periods when the car park is full. Moreover, drivers often idle with their engines running while waiting for a spot to become available, leading to increased engine heat emissions.

Solution

We have planned to design an Application Software “ ParkWise” to improve energy efficiency.

Function of App

Drivers who plan to make a trip down to Hougang Mall are able to use this app to reserve a slot.

Once their reservation of a parking slot has been confirmed, they will have a 10 minute grace period to park their car.

Once the slot has been reserved, the signal indicating the availability of parking spaces will turn red indicating its availability.

The app will provide the shortest and fastest route and direct drivers with directions to the parking slot so as to minimise engine heat emissions upon entering the car park.

Figure 1: App

The app that driver would use to reserve their parking slot

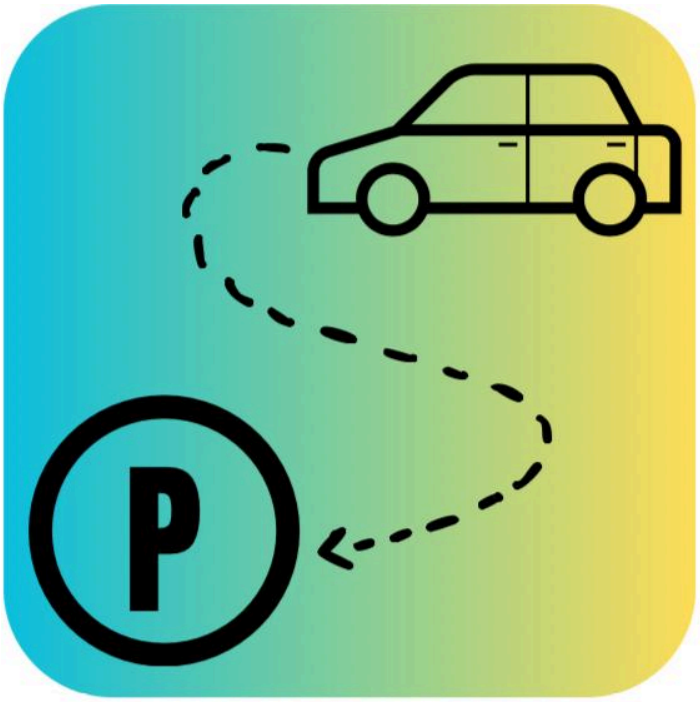


Figure two: drivers are able to select the mall that they want to park their car in

Figure three: drivers will be able to select an available slot

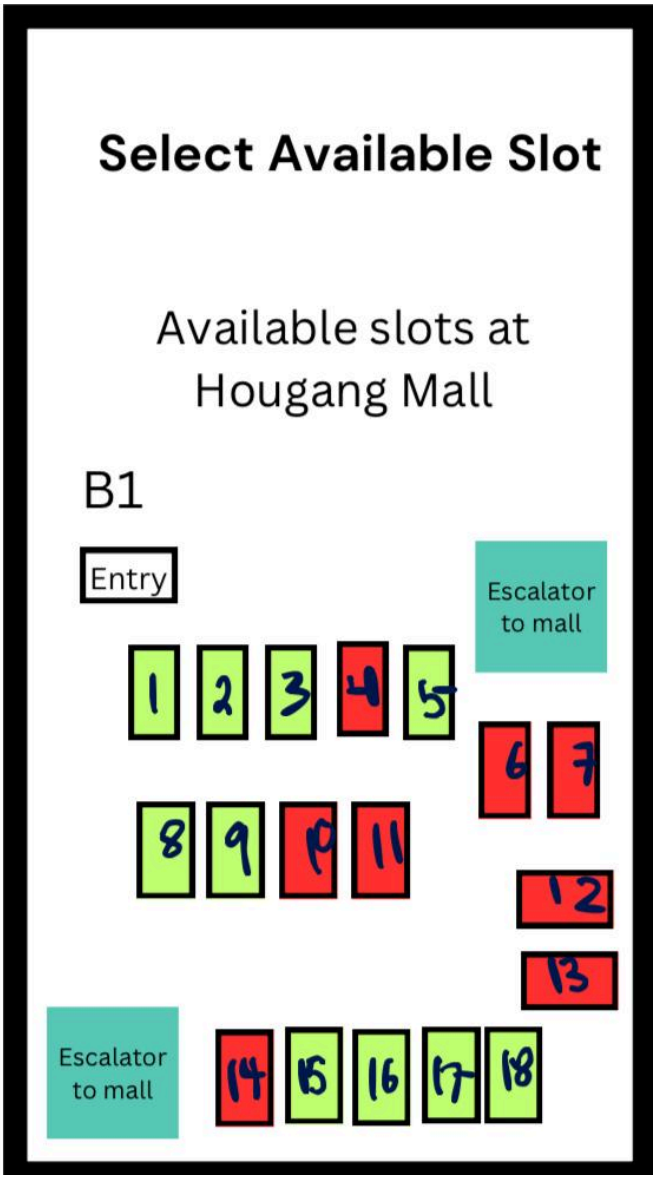
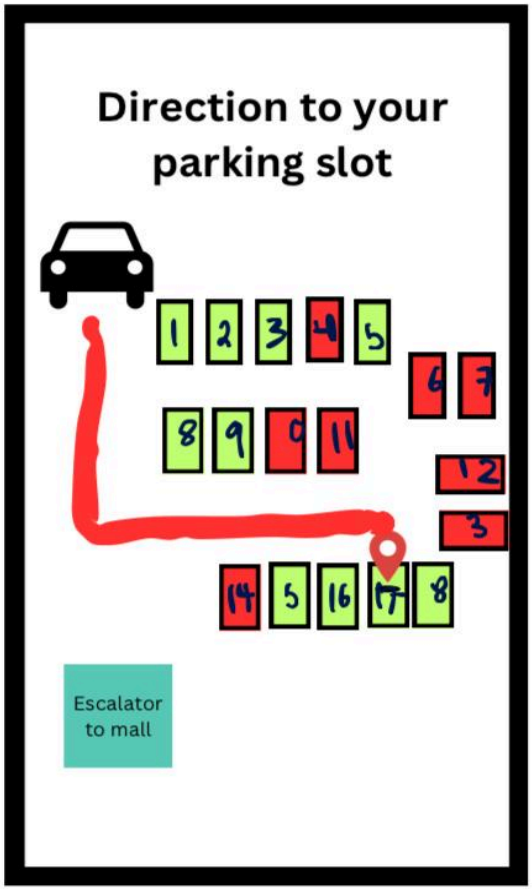


Figure Four: when drivers reach the car park, they are able to follow the fastest route to their slot



Pros

This could reduce carbon emissions significantly. Mobile applications being implemented outside of Singapore with similar purpose, had helped reduce the time required to find parking space by 6 minutes reducing vehicle emissions by 2010 grams of CO_2 per mile. This could also help to reduce congestion on roads caused by locating parking space for which produces a significant amount of unnecessary carbon emissions each year. The implementation of this application could hence reduce carbon emissions produced from looking for parking spots which is

equivalent to carbon emissions produced from the supply of electricity to many homes.

Additionally, the use of mobile applications allows for easy maintainability due to its low cost to maintain it. It is also rather accessible and convenient for users for which they could just access it via their mobile phones at their own comfort with no extra effort required. Constant maintainability of the app could be done via frequent updates enhancing each function of the app as well as allowing access to the necessary data accurately such as the change in time required to locate a parking slot.

Car Traffic in Hougang Mall on a daily basis	1200
Average distance to find a parking space before use of “Park Wise” (estimated)	4 rounds around carpark to find parking slots x 400m of circumference of carpark= 1600m= 1 mile travelled per car to find a parking slot
Per gram of CO2 emitted from locating of parking slot before use of “Park Wise” with the assumption that each mile releases 347 grams per mile	347 x 1200= 416400 grams per day
Average distance to find a parking space after use of “Park Wise” (estimated)	400m = 0.240 miles
Per gram of CO2 emitted from locating of parking slot after use of “Park Wise” with the assumption that each mile releases 347 grams per mile	0.240 x 347 x 1200= 99936 grams per day
Reduction in carbon emissions per day after the use of “Park Wise”	416400-99936= 316464 grams

As Hougang mall has a car traffic of 1200 on a daily basis and assuming each car covers a distance of a mile from finding parking spaces, this reduces carbon emissions by 316464 grams per day by reducing distance covered to locate a parking slot.

Cons

The development and maintenance of a mobile application may incur a high cost of an estimation of $10000 to develop the app and a monthly cost of around $2000 to maintain the app especially “Park Wise” may face the risk of being underutilised. Additionally, the successful implementation of this mobile application is highly dependent on the willingness of users to download and use it but some drivers may find it unnecessary. As such to encourage the downloads and utilisation of “Park Wise”, we could do it via incentives such as the accumulation of points in exchange for Fairprice vouchers. The points would be accumulated by the number of times they utilise the app to help get a parking spot. As such, this would help with encouraging more drivers to utilise the application to reduce carbon emissions as well as for more convenience. To increase driver’s awareness on the availability of this app, the mall could also help promote it by providing information around the mall such as near the car parks or in shops frequented by most drivers.

Introducing solar output sensitive window

In Singapore, a tropical nation with abundant sunlight, buildings tend to absorb significant heat through their windows. However, it's essential to balance this with optimising natural light entry. To address this, we have decided to introduce windows that are equipped with sensors that adjust based on surrounding solar output, ensuring optimal light levels while minimising heat absorption.

After much research, we have found that Onyx Solar [1]would provide the best solution to our strategy. Onyx Solar uses photovoltaic glass as a material for building purposes as well as an electricity-generating material, with the aim of capturing the sunlight and turning it into electricity. These glass would also allow natural light just like conventional glass. Photovoltaic glass panes can replace conventional glass in various architectural applications such as building facades, curtain walls, atriums, canopies, and terrace floors. Additionally, these glass panes can be installed on a wide range of existing buildings and facilities, enhancing them aesthetically and energetically.

[1] (*Sustainability - Self-Sufficient Buildings Thanks to Photovoltaic Glass.*, n.d.) from https://onyxsolar.com/about-onyx/sustainability

Advantage of using Onyx Solar Crystalline Photovoltaic Glass

1. It can provide buildings with a lot of natural illumination in their interiors.
2. Its filtering properties are also highlighted because both harmful UV radiation and IR can be absorbed, thus, improving its thermal insulation.
3. It offers flexibility in design since it can be tailored to architecture needs
4. Crystalline silicon glass installations take up less area for a given amount of kWp to be reached compared to amorphous silicon glass installations.
5. Ability to customise the light transmittance degree of crystalline silicon glass by spreading out the solar cells closer or farther apart.

Maintainability of using Onyx Solar Crystalline Photovoltaic Glass

Onyx Solar Crystalline Photovoltaic Glass has a durability of 25-30 years. It is designed to withstand harsh environmental conditions, including UV radiation, temperature variations, and mechanical stress.

Crystalline technology generally experiences lower degradation rates compared to other photovoltaic technologies. This means the glass will maintain its efficiency and performance over a longer period, reducing the need for replacements or extensive maintenance.

The only limitation would be the dust collection on the Photovoltaic glass panel. This would affect the amount of solar energy that can be converted into electrical energy. However, with Singapore's high total annual rainfall[2] of approximately 2200 mm, the dust would be removed via the rainwater, thus allowing the absorption of solar energy to still be efficient.

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[2] *Singapore - Climatology | Climate Change Knowledge Portal*. (n.d.). Climate Change Knowledge Portal. Retrieved July 15, 2024, from https://climateknowledgeportal.worldbank.org/country/singapore/climate-data-historical

Additionally, Crystalline photovoltaic panels are typically designed in a modular fashion, which means individual panels or cells can be replaced if they become damaged, without the need to replace the entire system. This modularity simplifies repairs and minimises downtime.

Cost Analysis

Energy consumption and cost without usage of Crystalline Photovoltaic Glass Panel

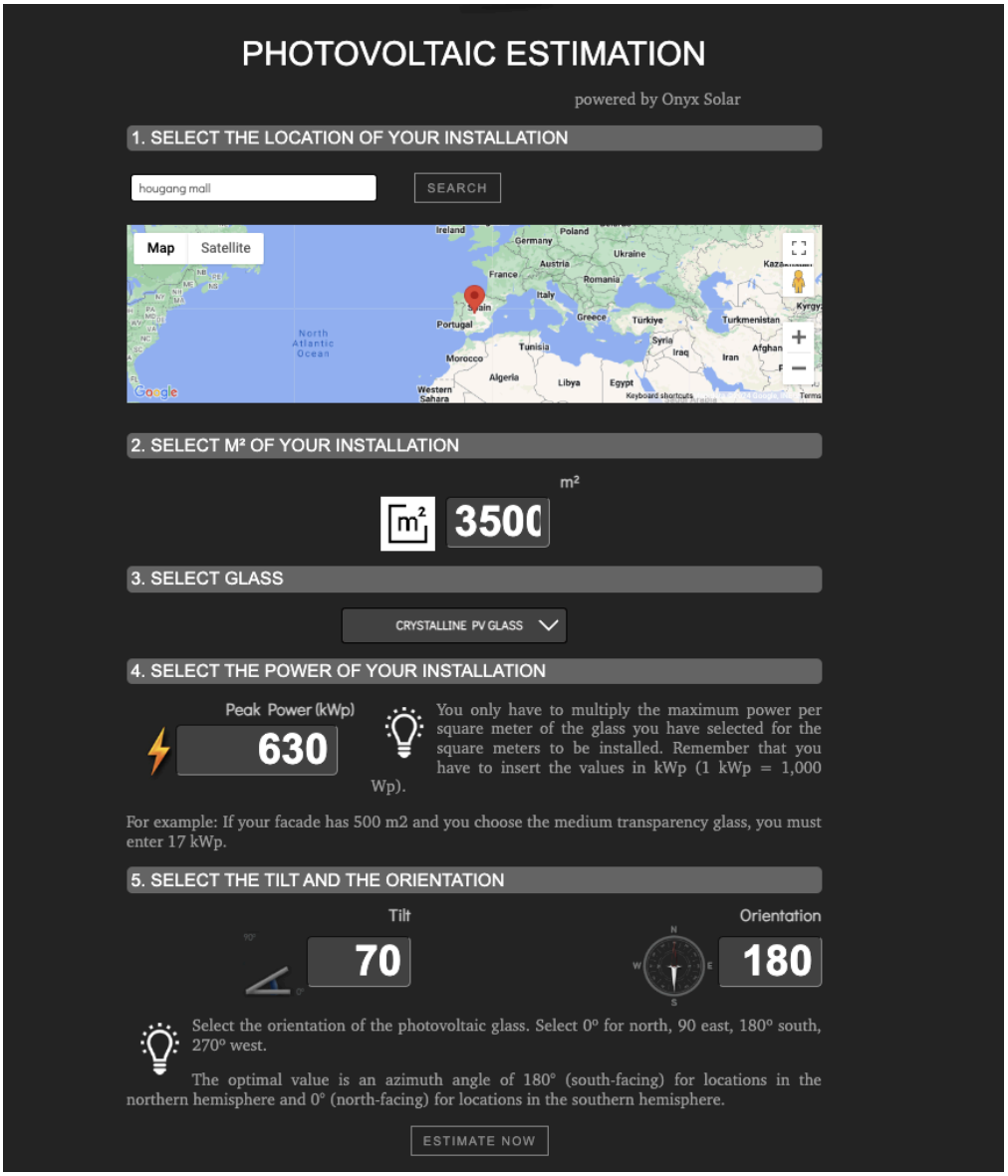
Total window area (including the rounded area and the windows on the wall)	3500m²
Total estimated electricity consumption in a year (landlord)	4320000 kwh
Total estimated electric bills in a year(landlord)	$1407024
Total estimated electricity consumption in a year (tenant)	8400000 kwh
Total estimated electric bills in a year (tenant)	$2735880
Total electrical bills (landlord + tenant)	$4142904

Energy consumption and cost with usage of Crystalline Photovoltaic Glass Panel

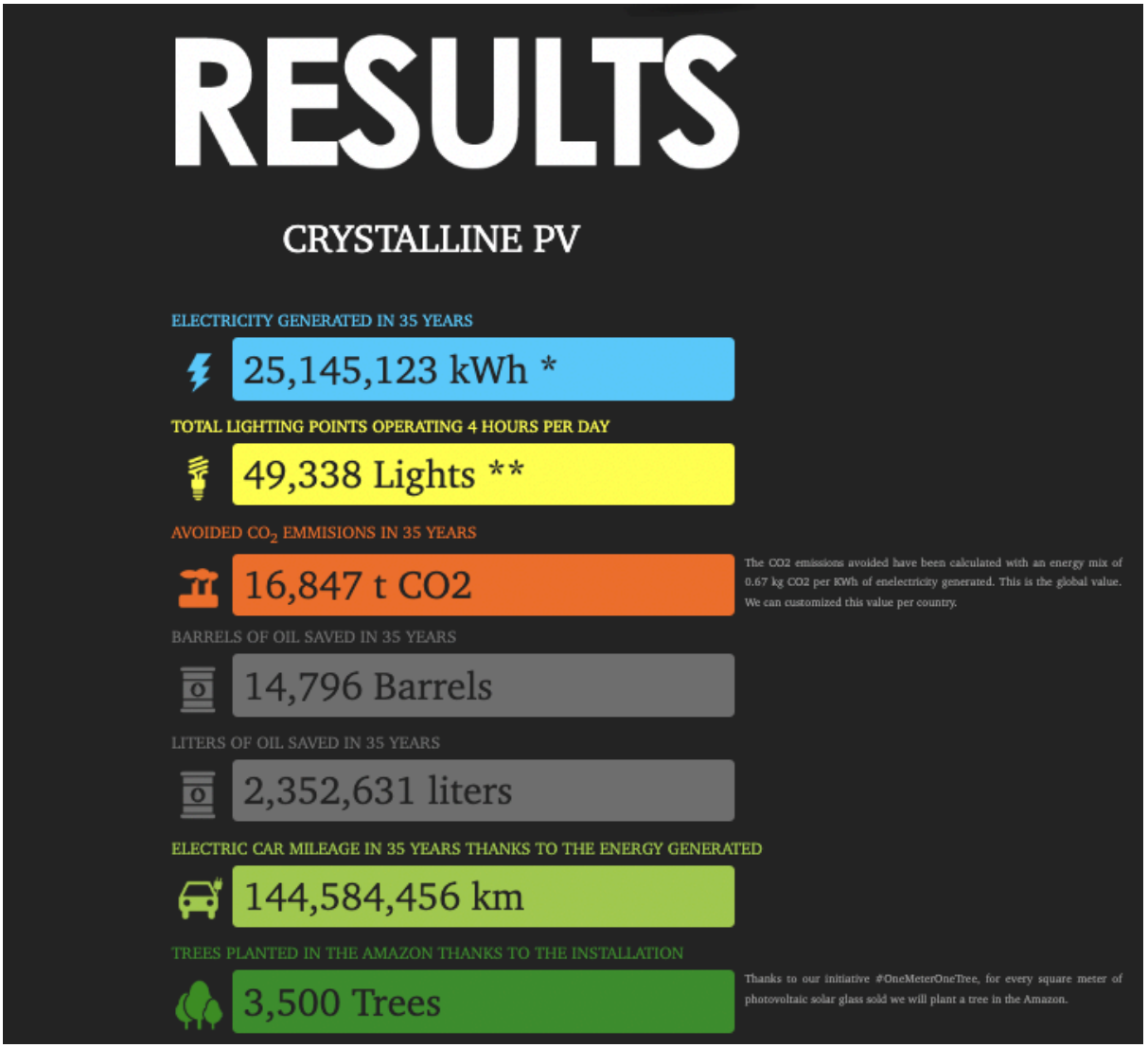
Estimated energy saved in a year with the use of crystalline windows	718432kwh
Amount saved in a year	$233993
Estimated final cost of electricity bills in a year	$3908910
Percentage cost saved in a year	5.648%
Estimated cost of one square metres of glass panel	$141
Total estimated cost of glass	$493500

To support our data, we have analysed the cost and savings based on the data provided from the Onyx Solar.

Estimated figures to calculate energy saving



Additional estimated results



Breakdown of estimated monthly energy saving

BY INSTALLING OUR SOLAR PV GLASS YOU CAN REACH

UP TO 8 LEED POINTS

RENEWABLE ENERGY PRODUCTION ON-SITE.....UP TO 3 POINTS

HEAT ISLAND REDUCTION.....UP TO 2 POINTS

OPTIMIZE ENERGY PERFORMANCE.....UP TO 2 POINTS

INNOVATIVE PRODUCT.....UP TO 1 POINTS

* The energy production is just an estimation where factors like surrounding shadows, self-shades or other external impacts have not been taking into account. These factors might lead to reduction in energy production. In addition, other potential losses due to BOS are also excluded from these calculations. The calculation has been done using PVGIS and PVWATTS.

** Calculated with energy efficient light bulbs of 12W

Month	E_d	E_m	H_d	H_m
January	2,234.66	69,274.41	4.09	126.71
February	2,371.88	66,412.59	4.37	122.49
March	2,678.83	83,043.79	5.03	155.98
April	2,323.87	69,716.03	4.41	132.18
May	2,236.07	69,318.31	4.33	134.29
June	2,203.74	66,112.27	4.36	130.94
July	2,429.11	75,302.36	4.85	150.45
August	2,708.15	83,952.65	5.35	165.79
September	2,722.84	81,685.33	5.26	157.67
October	2,618.87	81,184.85	4.93	152.79
November	2,074.39	62,231.64	3.83	114.95
December	1,849.89	57,346.59	3.39	104.94
Yearly average	2,371.03	72,131.74	4.52	137.43
Total for year		865,580.82		1,649.17

Ed: Average daily electricity production from the given system (kWh)

Em: Average monthly electricity production from the given system (kWh)

Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

NOTE: before using these calculations, you should read [ ]

ECONOMIC RESULT

Why Onyx Solar?

1. **Long term financial benefits**

Our PV Glass works as a revenue-accelerator. Enjoy long term energy savings, tax credits and incentives.

2. **Aesthetic Purposes**

Easy to adapt our PV glass to the needs of our customers making it possible to choose the shape, colour, size, thickness and grade of transparency of the glass therefore facilitating its integration in a wide range of projects and designs.

3. **Easy to install**

PV glass are easy to install even in existing buildings

4. **Onyx Solar is committed to sustainability**

Our aim is to enable the buildings to be self-sufficient from an energy point of view, a key factor in the struggle against climate change. We see our environmental-friendly solutions as a small contribution to create a meaningful change, needed to secure a sustainable legacy for generations to come.

5. **Onyx Solar is recognisable in Singapore**

There have been some buildings in Singapore that use Crystalline PV Glass for their buildings such as buildings at Tanjong Pagar. Located in the middle of Singapore's financial centre, this 64-storey tower is the tallest building in the country. Onyx contributed with the installation of a large photovoltaic canopy of 27,986 sq ft covering the main entrance to the building.

We believe that working together with Onyx Solar would bring about long term investment returns and would reduce the amount of energy consumption.

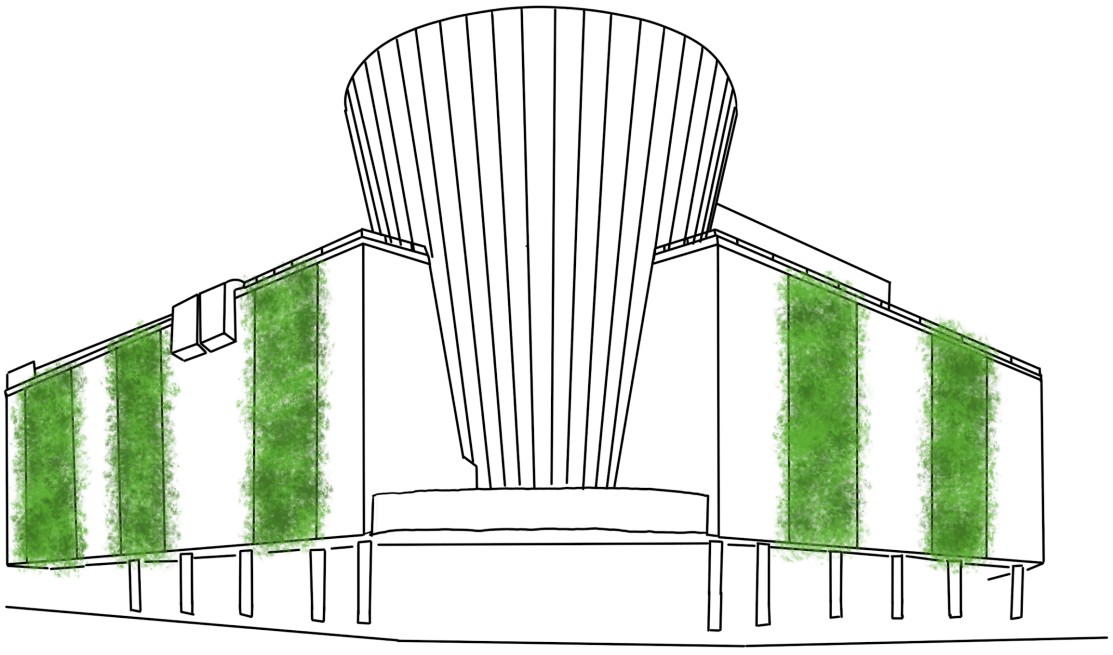
Proposed Improvement for Greenery Integration

Introducing vertical gardens

To integrate greenery into the building, we propose to do so using vertical gardens.

Vertical gardening takes up less space than traditional gardening, making it an easy way to integrate more greenery into the building. Vertical gardens can be lined along the outer wall of the mall as shown in diagram .

Figure 6: Illustration of vertical gardening on exterior walls of Hougang Mall



After much research, we have found that Vertiss vertical garden has the best suited solution to our strategy. Vertiss offers a comprehensive technical green wall solution for architects with a sustainable approach to cover walls with planted Expanded

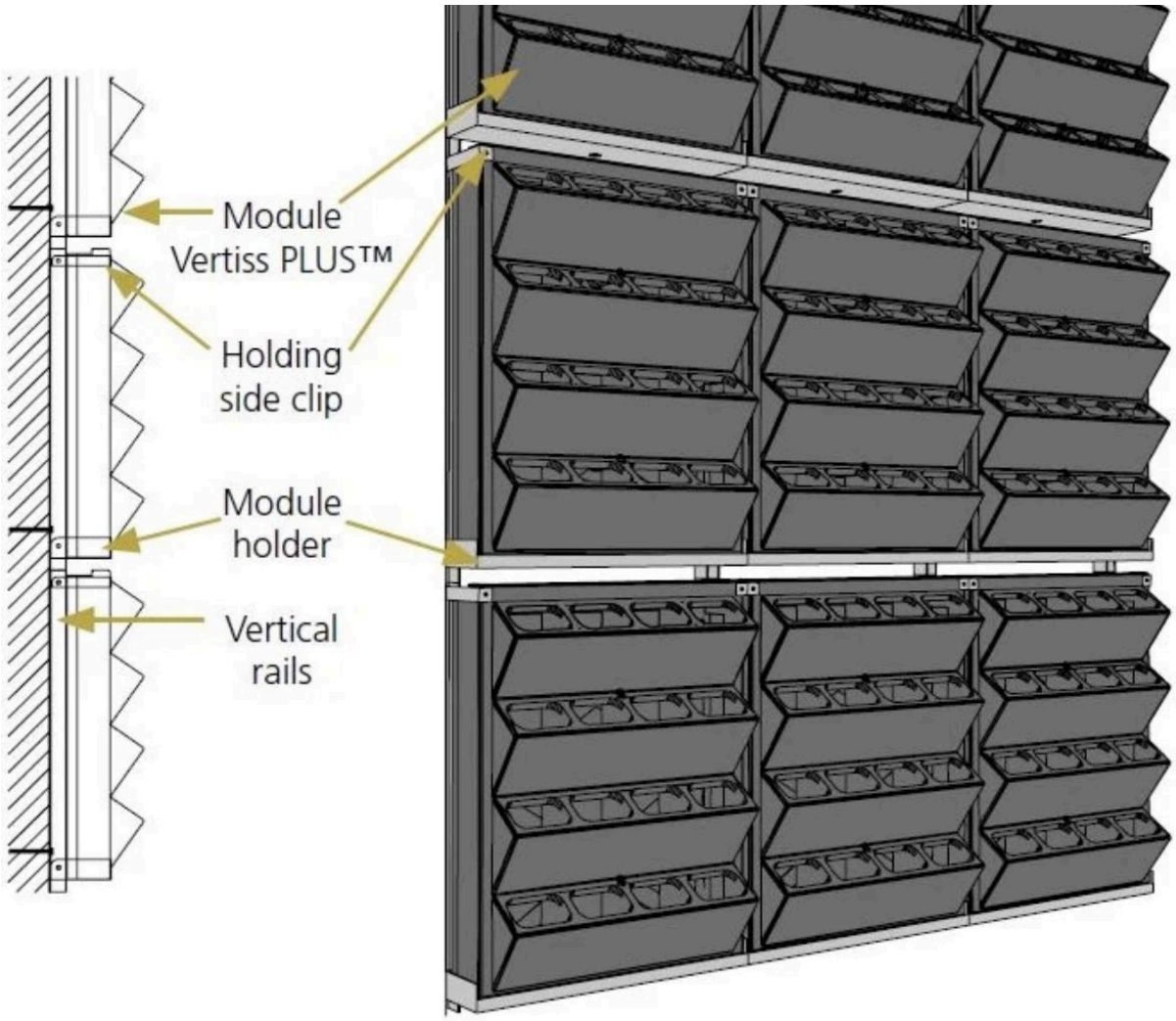
Polypropylene (EPP) modules and a metal structure to be mounted on the concrete walls. The vertical garden provided by Vertiss can be used to decorate all kinds of interior and exterior spaces such as terraces, swimming pool surroundings, patios, reception areas and of course building facades of Hougang Mall. Vertical garden also adds onto the property value of Hougang Mall[3] as the greenery of it will appeal to more patrons and as such, attract more patrons to visit for its healthy and aesthetic green environment.

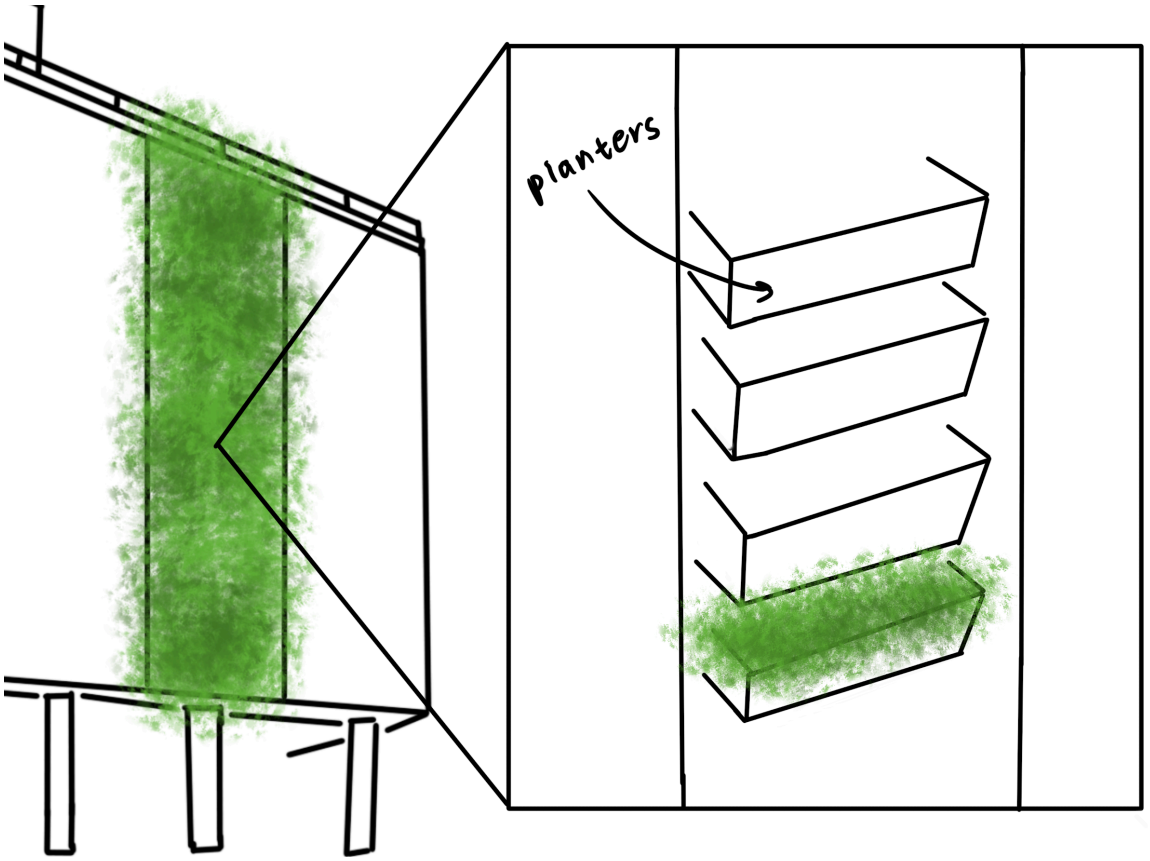
To set up the vertical garden along the walls, we would use a High Density expanded polypropylene (HP-EPP) module. This module is easy to install, resistant to corrosion and protects existing walls against UV rays allowing for the cost savings with respect to the thermal benefits obtained. As the planting cells of the module are inclined at an angle, it respects phototropism and geotropism, which are growth of plants in a direction determined by gravity. This subject plants to less stress when acclimatising and in the long term, the ergonomic design also allows for easy replacement of plants[4].

[3] Vertiss.net. Green wall design and property value, n.d. From https://www.vertiss.net/design-et-valeur-de-la-propriete-1?lang=en

[4] Vertiss.net. Vertiss Plus planting module, n.d. From https://www.vertiss.net/design-et-valeur-de-la-propriete-1?lang=en

Figure 7: HP-EPP modules on exterior walls of Hougang Mall





Pros

The HP-EPP module planters used with tropical ferns and bromeliads will create a lush, packed green wall as the plants grow and spread out. The plants, especially the sun-tolerant bromeliads, will absorb the heat from the sun and reduce the building's temperature, cooling the building down and could reduce the buildings use of and reliance on the existing cooling system. By having a vertical garden, it cools the environment near Hougang Mall by providing shade and releasing moisture into the air via evapotranspiration. This effectively reduces the need for a stronger air conditioning as it compensates for the heat generated by human activities and heat-absorbing properties of the building itself. Not only that, ferns are known to be plants that can improve air quality, so these walls can also absorb urban pollution such as noise and carbon dioxide, creating a more conducive environment and better air quality surrounding the mall. Overall, this in turn reduces the energy consumption and thus carbon emissions. These walls will also add a welcoming look and feel to the mall’s exterior.

Thermal Conductivity of ERR layer from the Vertiss module	0.04 W/ m.K
Temperature reduced for inside walls (buildings)	1.5°C
Total estimated electricity consumption in a year (landlord + tenant)	12,720,000 kWh
Total electrical bills (landlord + tenant)	$4142904
Carbon emission reduced in a year per 1°C rise in air condition temperature	10%
Carbon emission reduced in a year per 1.5°C rise in air condition temperature = 1.5°C fall in temperature of walls (buildings)	15%
Total carbon emission per year (landlord + tenant) (using OM GEF of 0.4168kg/ CO2/ kWh[5]	5,301,696 kg
Total carbon savings with the Vertiss module per year	795,254.4 kg
Total carbon emission with the Vertiss module per year	4,506,441.6 kg

Hence, there will be an overall carbon savings of near 800000 kg per year. Assuming an average car in Singapore emits about 6.4 million tonnes[6] of carbon per year, equating to 6400 kg. This is extremely significant as it is roughly equivalent to taking about 125 cars off the road for a year. The average annual electricity consumption of a four-room HDB household is equivalent to about 1.83 tonnes of carbon emissions

[5] Energy Market Authority. SES Chapter 2: Energy Transformation, 2023 from https://www.ema.gov.sg/resources/singapore-energy-statistics/chapter2

[6] Teh. Green vehicles add power to the fight against climate change. , Aug 22, 2021 from https://www.straitstimes.com/singapore/environment/green-vehicles-add-power-to-the-fight-against-climate-change#:~:text=Nearly%20a%20 million%20 vehicles%20 ply.for%20a%20great%20transport%20revolution.

annually[7] (1800 kg). Knowing that a tree absorbs approximately 25 kg of carbon dioxide annually[8]. This would be equivalent to approximately 31810 trees needed to sequester the 795254.4 kg of reduced carbon emissions. Thus it also goes to show that by having a vertical garden, it will offset a significant amount of carbon emissions. In turn, it allows for about 32000 trees to be saved if this vertical gardening is integrated into Hougang Mall. It illustrates a substantial reduction in environmental harms dealt to the environment and promotes a much more sustainable improvement in Singapore.

Additionally, the growing medium used is developed specifically for green walls. Some components of it includes the following:

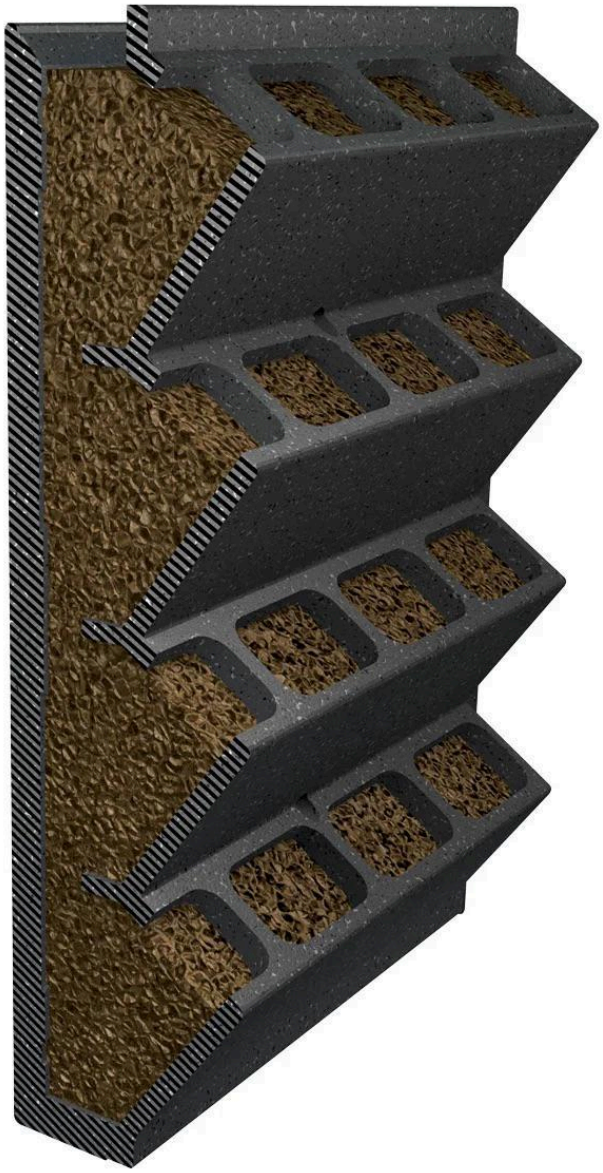
- Pozzolan and clay balls which provides excellent root anchorage and water retention alongside with good aeration and drainage even when saturated.
- Organic material (garden peat) which produces good all-round water retention, ensuring that plants can recover well after planting.
- Specific holding agents in the form of colloids improve water retention as it absorbs up to 300 times its weight in water and enhance

Figure 7: Growing medium for the module

[7] SP Group. My Carbon Footprint, May 2020 from https://www.spgroup.com.sg/dam/spgroup/wcm/connect/spgrp/78f7d811-9a10-4a3b-b864-a4afd1265117/%5B20200505%5D+Media+Release+-+My+Carbon+Footprint+Go+Green+While+Beating+The+Heat+and+Staying+Home.pdf?MOD=AJPERES&CVID=#:~:text=On%20a%20 household%20 level%2C%20the,90%20 rain%20trees%20 per%20 household.

https://frogparking.com/reduced-carbon-footprint-parking/

[8] EcoTree. How much CO2 does a tree absorb? Let's get carbon curious!, n.d. From https://ecotree.green/en/how-much-co2-does-a-tree-absorb#:~:text=A%20tree%20absorbs%20approximately%2025kg%20of%20CO2%20per%20year&text=But%20really%20a%20tree%20absorbs,a%20whole%20host%20of%20factors.



In summary, this growing medium allows for great water retention capacity as the water absorbed by it can be used to ensure root growth of plants. This leads to extensive water savings of up to $25149.90 reduction in the water bills annually as the water absorbed requires less effort for watering each time.

Area of 1 module (16 planting cells	0.48 m2

including fixing system)	
Area of x modules for the whole of Hougang Mall's exterior	53,510.32 m2
Number of modules needed for the whole of Hougang Mall's exterior	111480 approximately
Volume of growing medium for 1 module	32 litres
Volume of water the growing medium for 1 module can absorb up to	160 litres
Volume of water absorbed from growing medium for modules	17,836,773 litres approximately = 17836.773 m3
Price of water for Hougang Mall 2024	$1.41/ m3
Water savings from the water absorbed by 111480 modules	$25,149.84993 = approximately $25149.90
Total current carbon emissions from water consumption	11817.6 kg
Total carbon savings from growing medium (using 1 m3 water = 0.05kg carbon emitted[9])	891.83865 kg = 892 kg approximately
Total carbon emission with the growing medium	10925.76135 kg

Additionally, the carbon savings achieved from the module accounts for approximately up to 892 kg, which may not seem significant but still has a notable impact on the environment. Reducing 892 kg of carbon emission contributes towards the conservation of approximately 36 trees. This demonstrates how significant even seemingly small reductions in carbon emissions can be for our society. On a larger implication, this also enables Hougang Mall to take on the lead for sustainability efforts which builds a unique brand image and reputation among consumers.

[9] Hsien, Low, Chan Fuchen, Tan. Life cycle assessment of water supply in Singapore - A water-scarce urban city with multiple water sources, Dec 2019 from https://www.researchgate.net/publication/337662284_Life_cycle_assessment_of_water_supply_in_Singapore_-_A_water-scarce_urban_city_with_multiple_water_sources#:~:text=The%20carbon%20footprint%20to%20produce,e%20per%20cubic%20metre%2C%20respectively.

We would use a mix of tropical ferns such as shield ferns and wood ferns and sun-tolerant bromeliads for these walls. Since Singapore has a mean outdoor light level of 670.9 lux which is far more than sufficient for tropical ferns which thrives in partial sunlight, using both would be ideal for an outdoor vertical garden. They both require well-drained soil and little to no fertiliser, making them easy to care for by the rainwater harvester which will be mentioned below. Thus they are a suitable mix for an outdoor vertical garden.

Maintainability

Maintenance is advised to be done once per year to check the following;

1. Correct system operation
2. Moisture level of growing medium and alter the frequency of watering accordingly if necessary
3. Irrigation system which includes cleaning of the filter and fertilisation
4. Plants and their growth which includes phytosanitary treatment if necessary
5. Inspect the metal frame structure which holds the growing medium

Since the plants used require little to human care, majority of the maintenance efforts will be focussed on the module itself. Even so, only one maintenance session per year is required as stated by Vertiss. Annual maintenance of the vertical garden, which requires minimal commitments, effectively contributes towards more than proportionate improvements in terms of its efficiency and sustainability in the long-run, ensuring its longevity. Vertical farming allows for significant return in terms of reducing carbon emissions while supporting sustainable resource management to minimise environmental harms and reap the benefits of vertical farming.

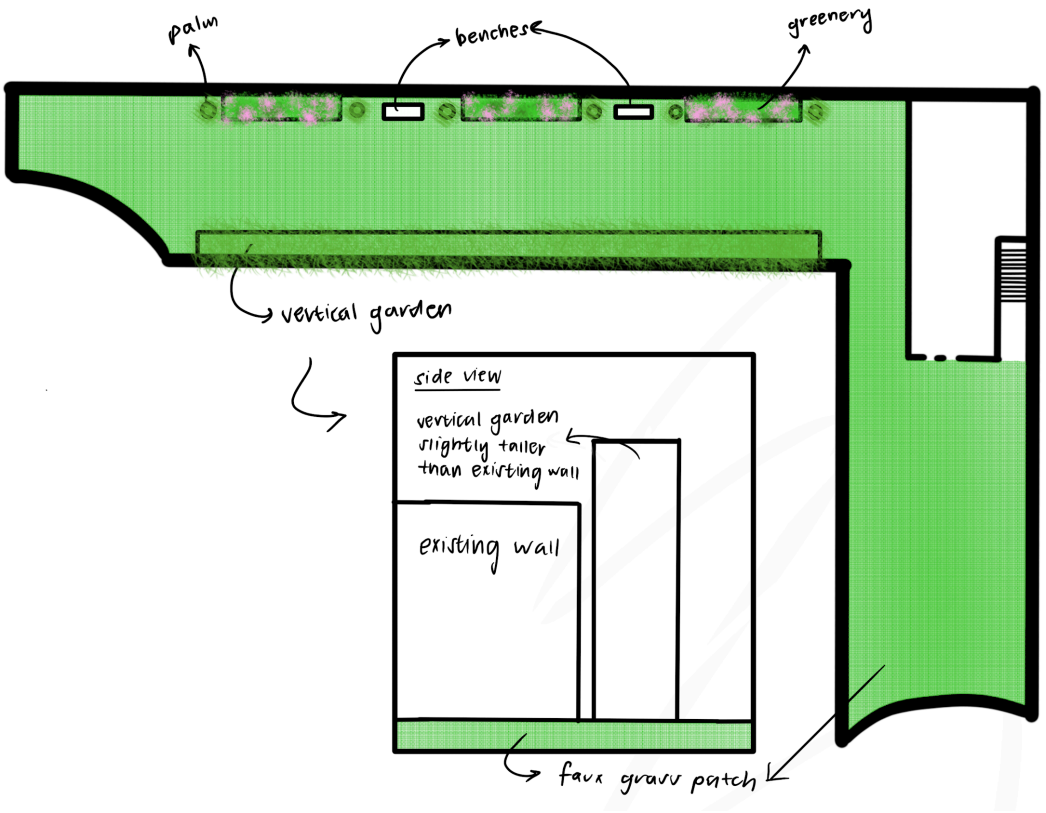
Cons

Nevertheless, the main limitations to vertical farming would be the high initial cost incurred. Since vertical farming requires specific infrastructure like the HP-EPP module which are found only in France, the start-up cost will definitely be high. This may thus lead to a financial strain on Fraser Property as funds may need to be channelled from other projects to fund for it. Thus, potentially risking Frasers to be in a financial debt and budget deficit if there is not enough funds to supplement for the set up for the vertical garden. Furthermore, return on investments for vertical gardens is rather slow as the primary benefits which have led us to integrate it into Hougang Mall are its environmental benefits which are non-tangible. This non-monetary benefit will not be immediately translated into financial gains via the cut of electricity bills in the short-term. Additionally, from the tenant's perspective, they will have to pay a higher rental due to the higher property value brought about by vertical gardening. Some tenants may be unwilling to pay higher rental despite the possibility of obtaining more gains in the long run due to status quo bias, which may inevitably lead to a failure to retain some of the tenants in Hougang Mall.

Rooftop Garden

The rooftop area is also another area where more greenery can be incorporated. Other than beautifying the area with plants like mini bamboo plants and bougainvillaeas, we can also introduce smaller scale vertical gardens as walls once again creating a more welcoming space for mall-goers as well as cool down the area by absorbing heat and transpiration. They can be placed such that it enhances the space but does not take up too much of it to still allow space for recreational use.

Figure 8: Rooftop Garden



Vertical gardens on the rooftop area can also serve as a vice for education, for residents and mall-goers to learn more about vertical gardening and its benefits. The plants we could grow on the rooftop vertical gardens can include vegetables commonly used for cooking in households such as long bean and chinese spinach. These plants require more attention and care, hence can be used as a way to educate residents and cultivate a mindset that it is more sustainable and wallet-friendly for one to grow their own vegetables. These plants can be harvested and donated to the low-income, especially those who do not have the means to grow their own vegetables such as elderly living alone.

On the rooftop, we would also like to introduce a rainwater harvesting system that is designed to integrate more greenery as well. It can be disguised as an elevated patch of faux grass covering the whole rooftop area as shown in figure 8. The rainwater will be collected under the grass patch such that recreational activities take place on the collector.

As mentioned, the collected rainwater will be used for watering the vertical gardens,

but its other uses and how the water system would work will be further elaborated on under water efficiency.

Proposed Improvement for Water Efficiency

Introducing Faux Grass Rainwater Harvester

Problem and solution

For more sustainable water management, we propose Hougang mall to implement rainwater harvesters disguised as an artificial turf on the rooftop terrace to collect rainwater as rainwater seeps through the artificial turf. We propose for the rainwater harvesters to be positioned as shown in the figure below.

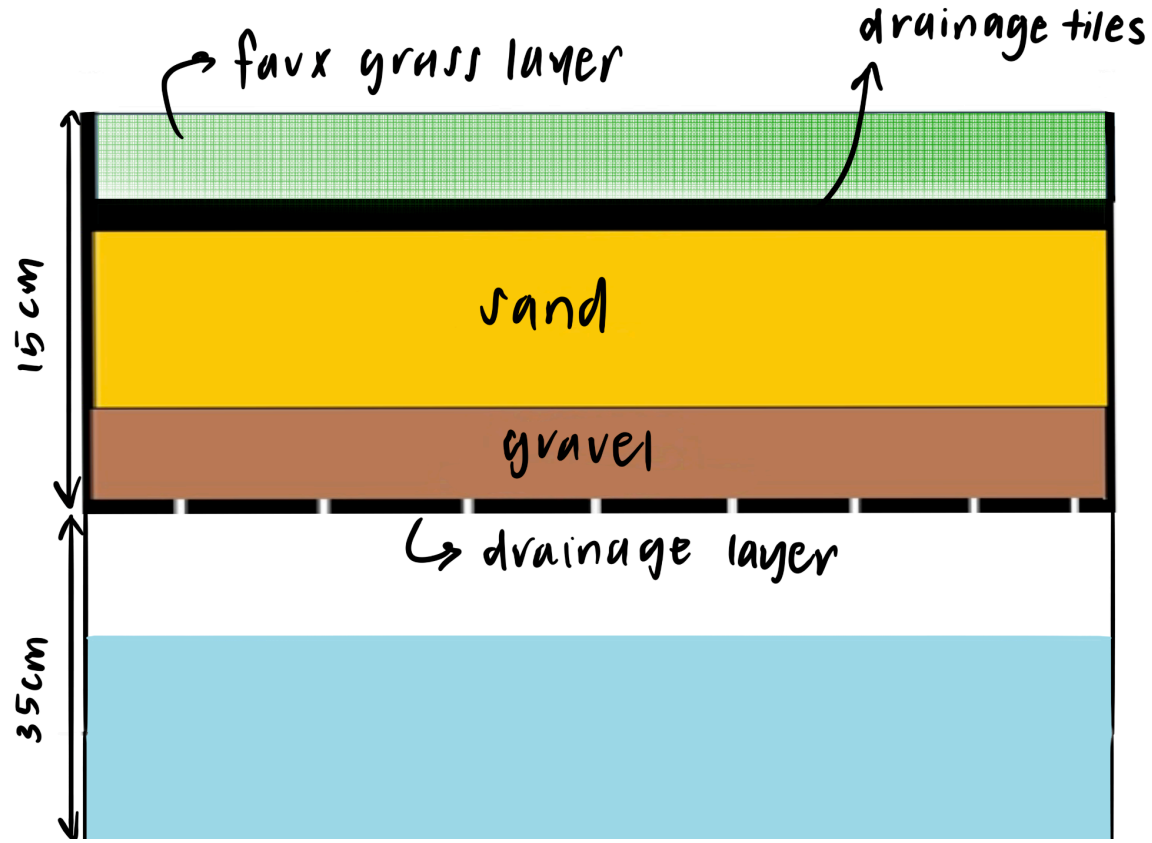
Figure 8: Placement of rainwater harvesters on rooftop

It will be a raised platform of about 50 cm and this will be the water storage tank. There will be no other external water storage tank. This is to allow mall-goers to still be able to use the space for their activities at the roof terrace. We also propose that the rainwater harvester be covered by the faux grass as it adds more greenery to the space and enhances consumer experience.

Function and structure of Rainwater Harvester

The water collected will be used for the outer vertical walls as mentioned in the section before as well as for flushing toilets (2% of domestic water consumption in landlord area) hence they will be connected to the pipe system for the vertical garden as well as directly-pumped to toilet cisterns. As the water is not used for potable water we are using a simple filtering system to filter out any dirt and debris. The faux grass will act as the first layer of filtering, followed by a simple sand bed water filter. (figure 9)

Figure 9: Cross section of rainwater harvester



Maintainability

Overall, the component of the entire system that has the shortest lifetime is the sand bed filtering system. Sand bed filtering systems typically have a lifespan of 7-10 years and would depend on how much filtrate it has collected[10], thus it would need to be replaced in a maximum of 10 years.

As for the faux grass layer, it will have to be cleaned regularly as it is exposed to the elements and is the first layer of filtering. A filtering system covered by faux grass has also not been experimented with yet thus may come with faults but faux grass was made to be permeable and for water drainage[11]. The faux grass and filtering system may also degrade faster when people conduct activities on it, hence must be monitored and maintained as well.

The maintainability of the pipe system for the vertical wall has been elaborated on in the previous section, and as for pipe system connecting to toilets, PVC toilet pipe systems have long lifespans of 24-50 years[12] and would only need to be cleaned once every month[13].

Pros

Estimated carbon savings (based on data obtained from timeanddate.com[14], researchgate.com[15] and estimated measurements using Google Earth)

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[10] (Miller, 2023) from https://hyclor.com.au/how-long-do-pool-filters-last/
[11] (*How Do Artificial Lawns Drain Water?*, n.d.) from https://www.astrowarehouse.com/how-do-artificial-lawns-drain-water/
[12] (*4 Signs It's Time to Upgrade or Replace Your Plumbing*, n.d.) from https://btacinc.com/4-signs-time-upgrade-replace-plumbing/
[13] (*How Often Should I Clean My Drains at Home?*, n.d.) from https://mrplumberindy.com/knowledge-center/how-often-should-i-clean-my-drains-at-home/
[14] https://www.timeanddate.com/weather/@1881948/climate
[15] (*Life Cycle Assessment of Water Supply in Singapore — A Water-Scarce Urban City With Multiple Water Sources | Request PDF*, n.d.) from https://www.researchgate.net/publication/337662284_Life_cycle_assessment_of_water_supply_in_Singapore_-_A_water-scarce_urban_city_with_multiple_water_sources

	Estimated water collected/m³	Total water consumption/m³	Existing total carbon emissions from water consumption/kg	Reduced carbon emissions with addition of rainwater harvester/kg	Carbon savings/kg
Per month	197.316	12310	984.8	970.32	14.48
Per year	1423.730	147720	11817.6	11760.7	56.9492

Estimated reduction in water bills is $278.22 per month

These values may differ as precipitation varies every month.

Cons

Estimated total cost (all costs are rough estimates based off the prices found from various vendors)

Average cost of faux grass + draining tiles	$20000++
Average cost of sand bed filtering system	$2330.50++
Average cost of concrete tank	$4000++
Average cost of pipe systems	$600++
Estimated total cost	$27000++

Hence one disadvantage is that the implementation of the rainwater harvester will incur large costs with the addition of maintainability costs.

Another disadvantage regarding safety is the elevated height of the tank. Although the walls of the rooftop terrace are about 3m, it can still pose a safety issue. How much weight the rainwater harvester can support also poses another safety issue and regulations will need to be in place to ensure safety.

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